

STRESS ANALYSIS AND OPTIMIZATION OF MEDIUM SIZE BUS ROOF FRAME USING FEM METHOD

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ABSTRACT

Mass transportation has an important role in Indonesian society. The number of bus passengers for daily activities is quite high. This study carried out optimization of the roof bus frame with the constraints of the value of von Mises stress and deflection resulted from the simulation of it subjected by static loading. The material used for the roof of this medium bus is Stainless Steel 1.4003 which is a material that has low corrosion rate and high ultimate tensile strength. The optimization process carried out in this study is sizing optimization which is an optimization by increasing or decreasing the thickness of the pipe size in certain areas that have critical stress or deflection. The model of the roof was drawn using solid work software and then it was exported to Hyperwork Altair software for simulation purposes with the significant load of model. Stress and deflection resulted from simulation were used as constraints in sizing optimization to get the optimum thickness of roof bus frame that can reduce the overall mass of frame. As a result of optimization, there is a reduction of 10.49% mass of overall roof bus frame.

KEYWORDS: Medium Bus Roof Truss, Sizing Optimization, Von Mises Stress, Deflection, Frequency & Bending Stiffness

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INTRODUCTION

Public transportation plays an important role in supporting the economic activities of the people in Indonesia. Public transportation in Indonesia varies from buses, trains and ships. Buses are motorized vehicles that are very important mass transportation. Starting from inter-city to inter-provincial. The data from the Directorate General of Land Transportation shows that in 2016 there were 22,742 buses in Indonesia. There are 843 autobus companies in Indonesia in 2016. In maintaining the safety of bus passengers, bus companies in Indonesia always prioritize the comfort and safety of passengers in order to compete with one another. The design of a medium bus roof truss is very important in the bus manufacturing process. Especially for the safety of the driver and passengers. The roof frame of a medium bus is a vehicle component whose main function is to strengthen the construction of the vehicle body to be able to withstand vehicle loads and impact loads during a collision so as to protect passengers [1].

The transportation sector increase significantly to meet the needs of the global market. Buses are still the main mode of transportation between cities. This vehicle from the beginning of its development until now there have been many changes such as in the shape, dimensions, and the driving force used. Many buses today still uses diesel as a fuel, but changes have been made to start to use electrical buses. In the vehicle structure, it is important

to pay attention to minimize the overall weight load applied during the vehicle's operation, since it can reduce the fuel consumption[2]–[6]. However, the overall weight of the structure needs to be considered as light as possible. The roof is part of entire vehicles structures, therefore, if the mass of roof can be reduced, it means overall mass of vehicle can be reduced as well. In order to minimize the roof frame, it is necessary to reduce the thickness of some parts of the roof frame without reducing the level of safety. Therefore, the optimization process was applied to the bus roof frame. The optimization of other parts such as chassis and body of vehicles or overall vehicle structures have been carried out by many researchers[7], [8], [16], [16]–[24], [9], [25], [10], [10]–[15]. Finite element method was chosen for the reason of cheap cost and complexity of the object of optimization [11], [13], [16], [16], [17], [22], [24], [26], [27]. Several methods of optimization such as adaptive single object and multiple object genetic algorithms also were applied by some researchers [28]. Some researcher applied size optimization[8], [12], [14] and some researchers using topological optimization[10], [10], [11], [18], [20], [24] in effort to reduce the overall weight of vehicles. In this paper, size optimization will be used since it is more appropriate with the bus roof frame model.

METHOD

Model of roof bus frame was depicted in Figure 1. It has 7584 mm of length and 2238 mm of width. The model has five main longitudinal members and ten cross members. Stress analysis simulation was done in order to get the value of stress and displacement that will be used as constraint for size optimization of roof bus frame. The information on the used material was displayed in Table 1. Statics load that was applied to the model define as mass of structure, mass of air conditioning system, sunroof and roof panel. Total mass is 410 kg. Constraints of the model was lying on the bottom of each pillars as fixed. Load and boundary condition shown in Figure 2.

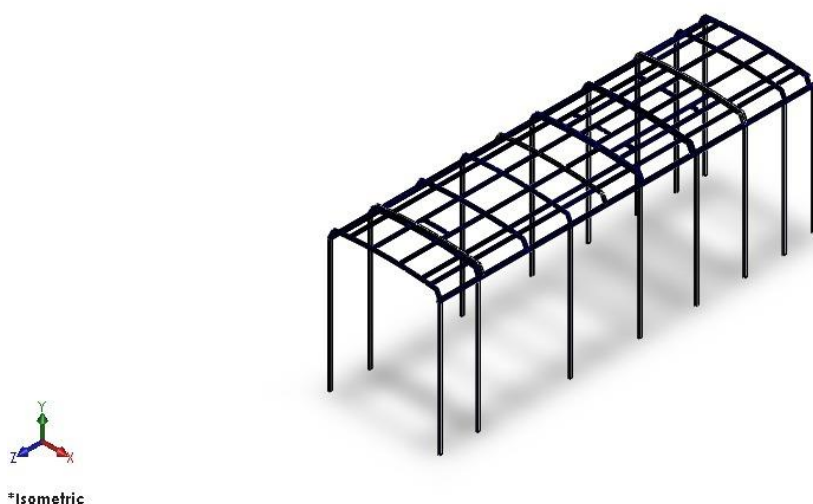


Figure 1: Roof Bus Frame Model.

Table 1: Material Properties of Roof Bus Frame

Properties	Stainless Steel	
Density	7700	Kg/m ³
Poisson ratio	0.3	
Yield Strenght	327	Mpa
Tensile Strenght	400	Mpa
Modulus Young	200	Gpa

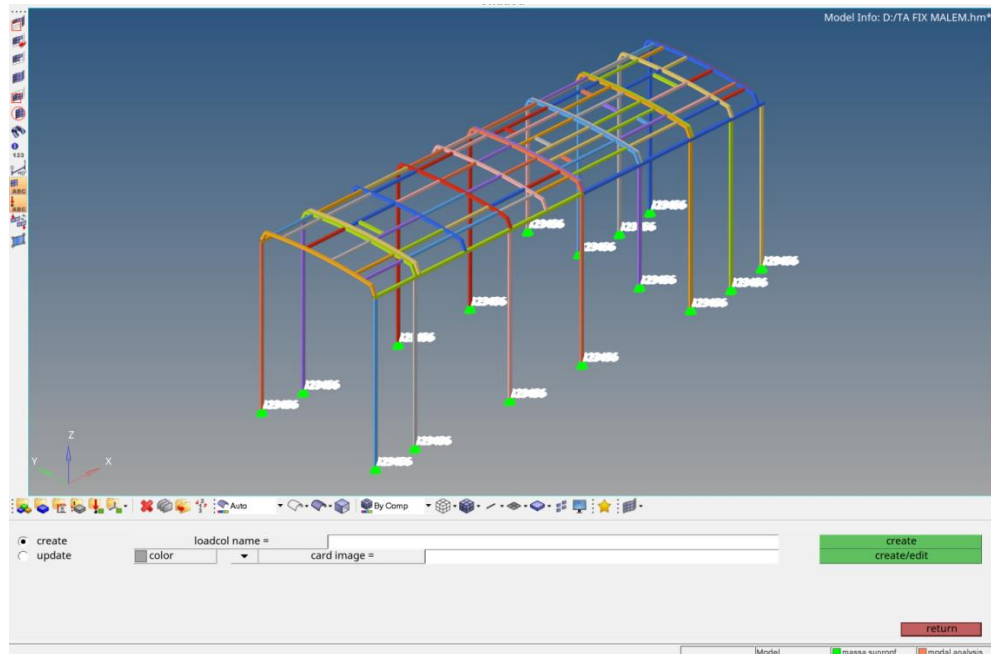


Figure 2: Load and Constraints of the Model.

Meshing study was done to obtain the optimum number of elements that resulted accurate output of simulation. The convergence test of the displacement is displayed in Figure 3. According to data in Figure 3, the optimum number of elements is 300000, therefore this number of element will be used in all the simulations in this research.

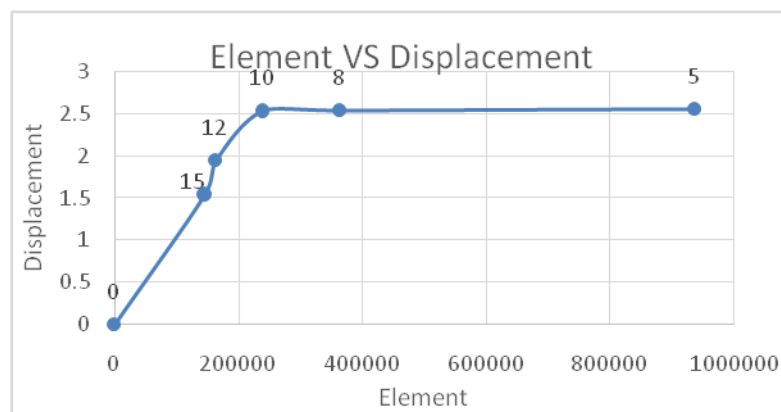


Figure 3: Convergence Test for Displacement Simulation.

In this study, the optimization of the bus roof truss structure uses a type of size optimization, where the thickness of the bus roof truss structure becomes a parameter in optimization. With the limits of maximum stress and maximum deflection from the results of the analysis of the static loading.

RESULTS AND DISCUSSIONS

Figure 4 and Figure 5 show the von Mises stress and displacement of roof bus frame subjected by static loading respectively. Maximum stress occurred at the end of cross member 4 connected with the longitudinal main member. The value of maximum von Mises stress is 112.022 MPa.

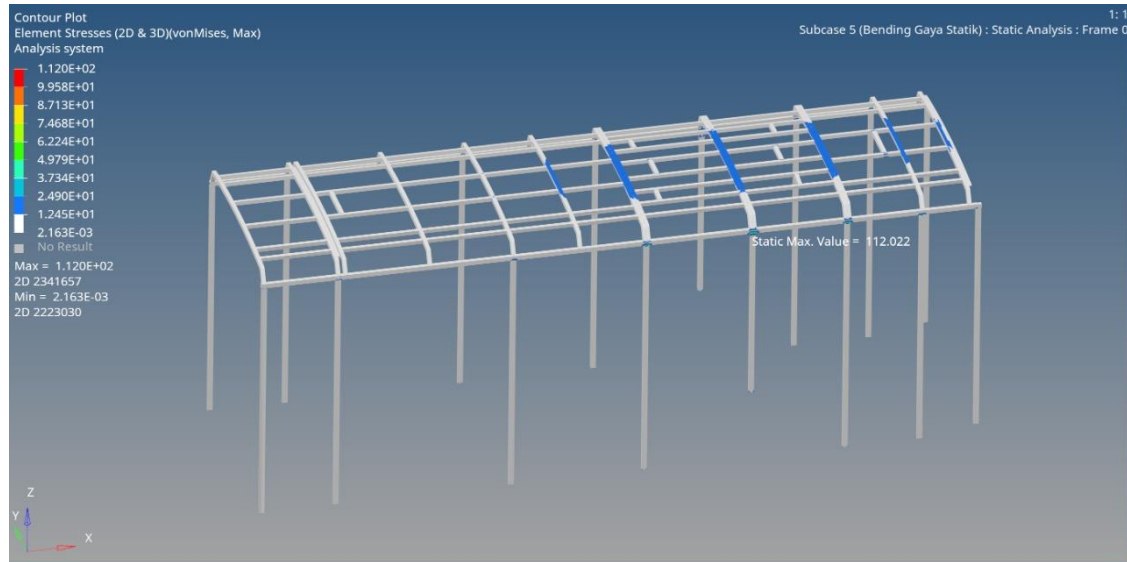


Figure 4: Von Misses Stress Distribution of Roof Bus Frame Model.

Meanwhile, the maximum deflection occurred at the middle of cross member 4 with the magnitude of 2.547 mm. The maximum von Misses stress and displacement value will be used as constrains value for the optimization process.

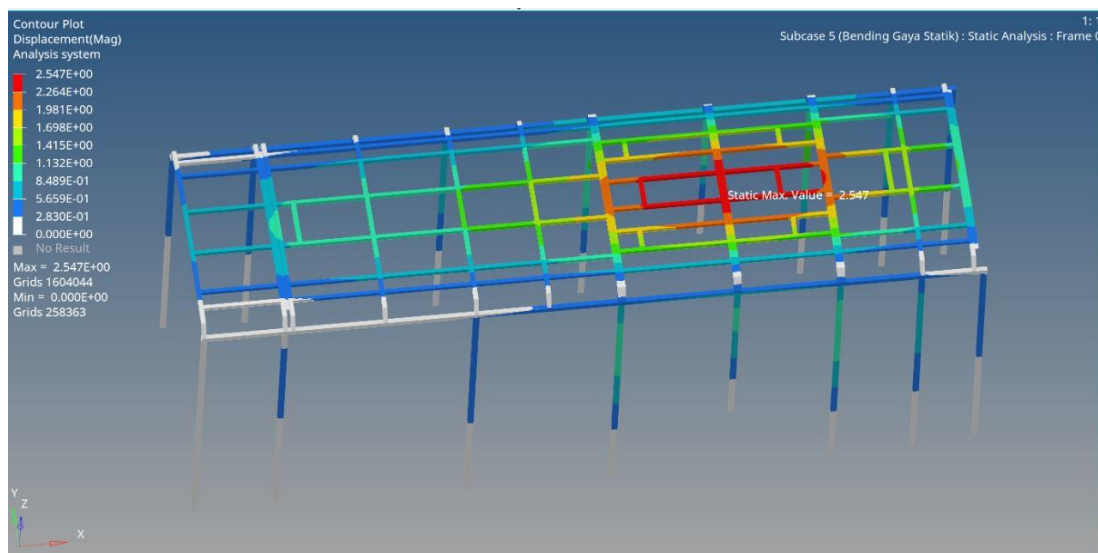


Figure 5: Displacement Distribution of Roof Bus Frame Model.

Before running the optimization solver stage, it is necessary to set the upper and lower limit values for the optimization constraints. For constraint displacement, the upper limit value entered is 3 mm while the lower limit value is 0 mm. The upper and lower limit values for the displacement and stress constraints are displayed in Figure 6 and Figure 7 respectively. For the stress constraint, the upper limit value entered is 150 MPa, while the lower limit value is 0 MPa.

Name	Value
Solver Keyword	DCONSTR
Name	DISPLACEMENT_X
ID	1
Include	[Master Model]
Response	(2) X_DISPLACEMENT
List of Loadsteps	1 Loadsteps
Lower Options	<OFF>
Upper Options	
Upper Options	Upper bound
Upper Bound	3.0
PROB	

Figure 6: Upper and Lower Limit Values on Constraint Displacement.

Name	Value
Solver Keyword	DCONSTR
Name	STRESS
ID	3
Include	[Master Model]
Response	(4) STRESS
List of Loadsteps	1 Loadsteps
Lower Options	<OFF>
Upper Options	
Upper Options	Upper bound
Upper Bound	150.0
PROB	

Figure 7: Upper and Lower Limit Values on Constraint Stress.

The following is an explanation of the optimization carried out in this study. For optimization 1 and 2 using continuous design variables. The results of the continuous design variable, the thickness number of the optimization results is random according to the specified range. In optimization 1 using 86 optimization parts and optimization 2 using 8 optimization blocks. Therefore optimization 1 will produce 86 optimization results measures and optimization 2 will produce 8 optimization results sizes. 8 blocks are selected based on structures that have similar geometries and sizes. Optimization 3 and 4 is the same as optimization 1 and 2. The difference is just that optimization 3 and 4 use a discrete design variable so that the results of the optimization will be in accordance with the size value that has been entered so that it is easier to implement in the industry. The thickness range used in continuous design variables is 1-3 mm, while for discrete design variables using the same range, namely 1-3mm, but adding a discrete value, namely: :1 1.2 1.5 1.8 2 2.1 2.3 2.5 2.7 2.8 (according to the size of the pipe in the industry)

The optimization process resulted in changes of thickness of several group of part of roof bus frame. Figure 8 shows the change of thickness in overall of frame of optimization 2 iteration 4. The value of thickness represented by the colour in the legend of the figure.

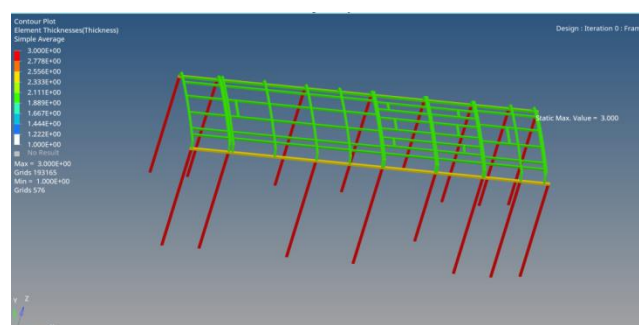


Figure 8: The Change of Thickness Member after the Optimization.

The overall result of 4 optimizations were shown in Table 2. Based on data in Table 2, the minimum overall mass was shown by optimization 1. The mass decrease from 427.2 Kg to 382.4 Kg, it resulted in decreasing about 10.486 %. This reduction of mass affects the performance of vehicles such as reducing fuel consumption and also the improvement of aerodynamic performance.

Table 10: Result of Optimization

No.	Output	Initial Design	Optimization 1	Optimization 2	Optimization 3	Optimization 4
1	Displacement (Mm)	2.547	2.692	2.598	2.678	2.567
2	Stress (Mpa)	112.002	112.301	112.198	112.275	112.134
3	Mass (Kg)	427.2	382.4	387	384.5	388.5
4	Safety Factor	2.9196	2.9118	2.9145	2.9125	2.9162

CONCLUSIONS

The static simulation and optimization of the roof bus frame has been completed successfully using packaged software. The static simulation resulted in von Misses stress and displacement that already used as constraints to minimize the mass of the roof bus frame. The optimizations reduce the thickness of some roof bus frame's member that resulted the decreasing mass of the roof frame by 10.486 %. The mass reduction of the bus roof frame is expected to improve the overall bus performance.

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REFERENCES

1. C. W. B. Alfred G. Striz, Weilong Chen, "No Title," *Static Anal. Struct. by Quarature Elem. Method*, 1993.
2. M. Mammetti, D. Gallegos, A. Freixas, and J. Muñoz, "The influence of rolling resistance on fuel consumption in heavy-duty vehicles," *SAE Tech. Pap.*, vol. 2, 2013, doi: 10.4271/2013-01-1343.
3. D. C. Biggs and R. Akcelik, "Estimating effect of vehicle characteristics on fuel consumption," *J. Transp. Eng.*, vol. 113, no. 1, pp. 101–106, 1987, doi: 10.1061/(ASCE)0733-947X(1987)113:1(101).
4. R. Tolouei and H. Titheridge, "Vehicle mass as a determinant of fuel consumption and secondary safety performance," *Transp. Res. Part D Transp. Environ.*, vol. 14, no. 6, pp. 385–399, Aug. 2009, doi: 10.1016/J.TRD.2009.01.005.
5. I. Carvalho, T. Baier, R. Simoes, and A. Silva, "Reducing fuel consumption through modular vehicle architectures," *Appl. Energy*, vol. 93, pp. 556–563, 2012, doi: 10.1016/j.apenergy.2011.12.004.
6. J. Decicco and M. Ross, "Recent advances in automotive technology and the cost-effectiveness of fuel economy improvement," *Transp. Res. Part D Transp. Environ.*, vol. 1, no. 2, pp. 79–96, Dec. 1996, doi: 10.1016/S1361-9209(96)00001-6.
7. C. C. Lin, S. J. Huang, and C. C. Liu, "Structural analysis and optimization of bicycle frame designs," *Adv. Mech. Eng.*, vol. 9, no. 12, 2017, doi: 10.1177/1687814017739513.
8. "Structural Optimization of Automotive Chassis : Theory, Set Up, Design Marco Cavazzuti and Luca Splendi (joint with Luca D ' Agostino, Enrico Torricelli, Dario Costi and Andrea Baldini) MilleChili Lab, Dipartimento di Ingegneria Meccanica e Civile," no. April, 2012.

9. T. Zhan, M. Ji, and F. Shang, "Stress distribution optimization of the optical fiber with multiple stress elements," *Opt. Fiber Technol.*, vol. 54, p. 102078, Jan. 2020, doi: 10.1016/J.YOFTE.2019.102078.
10. M. S. B. A. Razak, M. H. Bin Hasim, and N. A. Bin Ngatiman, "Design of Electric Vehicle Racing Car Chassis using Topology Optimization Method," *MATEC Web Conf.*, vol. 97, no. January, 2017, doi: 10.1051/mateconf/20179701117.
11. I. Tikekar and A. Damle, "Weight Reduction of Heavy Duty Truck Chassis Through Material Optimization," *Int. J. Eng. Res. Gen. Sci.*, vol. 4, no. 3, pp. 140–146, 2016, [Online]. Available: www.ijergs.org.
12. M. Cavazzuti and L. Splendi, "Structural Optimization of Automotive Chassis: Theory, Set Up, Design," *Italy Univ. degli Stud. di Modena e Reggio Emila*, 2011.
13. I. Haryanto, A. Raharjo, O. Kurdi, G. D. Haryadi, S. P. Santosa, and L. Gunawan, "Optimization of Bus Body Frame Structure for Weight Minimizing with Constraint of Natural Frequency using Adaptive Single-Objective Method," *Int. J. Sustain. Transp. Technol.*, vol. 1, no. 1, pp. 9–14, 2018.
14. H. Singh, "Optimization of Bus Body Structure Using OptiStruct," pp. 1–5.
15. K. Dalal and C. M. Choudhari, "Optimization of 40 Feet Trailer Chassis Based on Structural Static Simulation," *Int. J. Mech. Prod. Eng.*, no. 5, pp. 2320–2092, 2017, [Online]. Available: <http://iraj.in>.
16. H. Patel, K. C. Panchal, and C. S. Jadav, "Structural Analysis of Truck Chassis Frame and Design Optimization for Weight Reduction," *Int. J. Eng. Adv. Technol.*, vol. 2, no. 4, pp. 665–668, 2013, [Online]. Available: http://www.academia.edu/8039947/Structural_Analysis_of_Truck_Chassis_Frame_and_Design_Optimization_for_Weight_Reduction.
17. Chandan S N, Vinayaka N, and Sandeep G M, "Design, Analysis and Optimization of Race Car Chassis for its Structural Performance," *Int. J. Eng. Res.*, vol. V5, no. 07, pp. 361–367, 2016, doi: 10.17577/ijertv5is070313.
18. P. Naik, J. Unde, and B. Darekar, "Structural Analysis and Optimization of Hyperloop Pod," pp. 2–7, 2018.
19. E. Teipen and M. Paas, "Body Structure & Chassis Optimization," 2011.
20. A. A. Al-Tamimi, C. Peach, P. R. Fernandes, A. Cseke, and P. J. D. S. Bartolo, "Topology Optimization to Reduce the Stress Shielding Effect for Orthopedic Applications," *Procedia CIRP*, vol. 65, pp. 202–206, 2017, doi: 10.1016/j.procir.2017.04.032.
21. A. K. S. and A. V. H. Jatin Rajpal, Rucha S. Bhirud, "Finite Element Analysis and Optimization of Automobile Chassis," *Int. J. Innov. Technol. Res.*, vol. 3, no. 7, pp. 2075–2082, 2015, doi: 10.1016/j.compstruct.2012.07.019.
22. P. Chinta and D. L. V. V. Rao, "A New Design and Analysis of BUS Body Structure," *IOSR J. Mech. Civ. Eng.*, vol. 11, no. 5, pp. 39–47, 2014, doi: 10.9790/1684-11513947.
23. Akhyar, Husaini, H. Iskandar, and F. Ahmad, "Structural simulations of bicycle frame behaviour under various load conditions," in *Materials Science Forum*, 2019, vol. 961 MSF, pp. 137–147, doi: 10.4028/www.scientific.net/MSF.961.137.
24. H. Mishra, "Design Modification for Weight Reduction and Structural Analysis of Eicher 11.10 Chassis Frame," vol. 3, pp. 1614–1618, 2017, [Online]. Available: www.ijariie.com296.
25. A. H. Kumar and V. Deepanjali, "Design & Analysis of Automobile Chassis," *Int. J. Eng. Innov. Technol.*, vol. 5, no. 1, pp. 187–196, 2016, [Online]. Available: http://www.ijesit.com/Volume 5/Issue 1/IJESIT201601_23.pdf.
26. S. N. Vijayan and S. Sendhilkumar, "Structural Analysis of Automotive Chassis Considering Cross-Section and Material," *Int. J. Mech. Eng. Autom. Struct.*, vol. 2, no. 8, pp. 370–376, 2015.

27. D. Croccolo, M. De Agostinis, and N. Vincenzi, "Structural analysis of an articulated urban bus chassis via FEM: A methodology applied to a case study," *Stroj. Vestnik/Journal Mech. Eng.*, vol. 57, no. 11, pp. 799–809, 2011, doi: 10.5545/sv-jme.2011.077.
28. M. S. M. Sani, N. A. Nazri, S. N. Zahari, N. A. Z. Abdullah, and G. Priyandoko, "Dynamic Study of Bicycle Frame Structure," in *IOP Conference Series: Materials Science and Engineering*, 2016, vol. 160, no. 1, doi: 10.1088/1757-899X/160/1/012009.
29. Saravanan, A., et al. "Static analysis and weight reduction of aluminum casting alloy connecting rod using finite element method." *Int J Mech Prod Eng Res Dev (IJMPERD)* 8.3 (2018).
30. Saravanan, A., et al. "Design and analysis of trestle hydraulic jack using finite element method." *International Journal of Mechanical and production Engineering Research and Development* 8 (2018): 437 448 (2018).
31. Juliyana, S. Jebarose, et al. "Finite Element Analysis of Mono Composite Leaf Spring of Varying Thickness and Varying Width used in Automotives." *Int Journal of Mechanical and Production Engineering Research and Development* 7.6 (2017): 247-254.
32. Abdul, Kadir Muhammad, Okamoto Shingo, and Hoon Lee Jae. "Comparison Between the One Piezoelectric Actuator and the Two Ones on Vibration Control of a Flexible Two-Link Manipulator Using Finite Element Method." *International Journal of Mechanical Engineering (IJME)* 5.1 (2016): 27-44.